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Using foraminifera to identify overwash deposits in St Vincent Island, Florida in the wake of Hurricane Michael

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By

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Abstract

Major hurricanes have geomorphic and stratigraphic impacts in coast environments that can be used to identify and characterize the storms. One of the approaches to identify storm impact is by studying assemblage of foraminifera, small organisms that live primarily in marine environments with some species living in marshes, in coastal marshes or ponds, with the assumption that storm-induced overwash flooding brings marine species ashore. Hurricane Michael made landfall ~40 km northwest of St Vincent Island (SVI), Florida, on October 10, 2018, as a Category 5 storm. The storm surge of Michael inundated a large part of SVI, which offers a rare opportunity to investigate foraminifera assemblage of overwash deposits caused by an extremely powerful landfalling hurricane. In this study, samples from a sediment core taken from a marsh pond in SVI were analyzed for foraminifera assemblage. The analysis focuses on core top sediment interpreted as the Michael event layer, additional deeper sandy layers similar in grain size to the core top sediments, and clayey pond deposits. The core top sediment contained a higher abundance of foraminifera tests including *Ammonia* spp. and *Elphidium* spp. that can be traced to the bay east of SVI in comparison to the clayey pond deposits with little to no representation of forams in the deeper depths. This suggests that foraminiferal assemblage in the pond sediment may complement grain-size analysis for paleo tempestite identification in SVI, but only for the relatively recent events. At deeper depths the preservation is poor, resulting in the destruction of forams.

1. Introduction

With winds of over 111 miles per hour and carrying large amounts of moisture, major hurricanes are events that may leave drastic geomorphic and stratigraphic signatures in coastal environments. These signatures can be used to identify similar events of the past, which may be used to predict their occurrence. Storm surge from such intense storms are able to bring in a massive flux of sediment, which can contain identifiable characteristics. Major hurricane events can be identified by looking at the grain sizes of sediment in environments affected by the storm surge (Donnelly and Woodruff 2007, Lane et al 2011, van Hengstum et al 2015). Coarser grain size that are composed of siliciclastic sand, carbonate shells and shell fragments are transferred from marine environments (Donnelly and Woodruff 2007). Grain size analysis can provide the grain size unique to the environment that was impacted. Although grain size is a good indicator of energetic events such as storms, problems arise with sites that have low accumulation rates for sediment, strong tide impact, and local inland flooding. These conditions are indicators of below average amount of storms than indicated by isotopic proxies (Lane et al 2011).

Major storm layers may also be identified through looking at the assemblage of foraminifers (forams). Forams are single cell organisms that live primarily in marine environments, with several species that live in marshes and coastal ponds. Higher salinity tends to lead to an increase in the amount of calcareous forams, such as *Ammonia spp.* and *Elphidium spp.* (Osterman et al 2009). Marsh forams are excellent indicators of elevation and salinity tolerance, due to their abundance and low species diversity at (Kemp et al 2009). Marine forams can be carried into non-marine environments in the sand deposits that are carried by flooding (Lane et al 2011). Non-native forams are generally only found in marsh environments as a result of large weather events, such as hurricanes (Lane et al 2011, Hippensteel 2008). In general marshes are very sensitive to overwash from intense hurricanes, making them an ideal location for to study large scale events (Lane et al 2011).

The objective of this study was to determine if foraminifers are an effective method to identify major hurricane events by correlating foraminifer assemblages with predetermined event layers in Gadwall Lake, Florida. Nonevent layers were also examined to determine the reliability of the grain size ability to identify event and nonevent layers. Event and nonevent layers have shown that Gadwall Lake, Florida has evidence of being a location of extreme events.

Hurricane Michael was a category five hurricane that made landfall near Mexico Beach, Florida, on October 10, 2018. Roughly 40 kilometers southeast of the landfall, St. Vincent Island experienced category five winds, and a maximum storm surge of 2.9 meters. Gadwall Lake is one of the lakes on St. Vincent Island that was affected by the storm surge, and inundated with water and sediment from Apalachee Bay. This lake was chosen as a study site due to its close proximity to Apalachee Bay (Figure 1). Gadwall Lake was likely the most affected lake on St. Vincent Island.

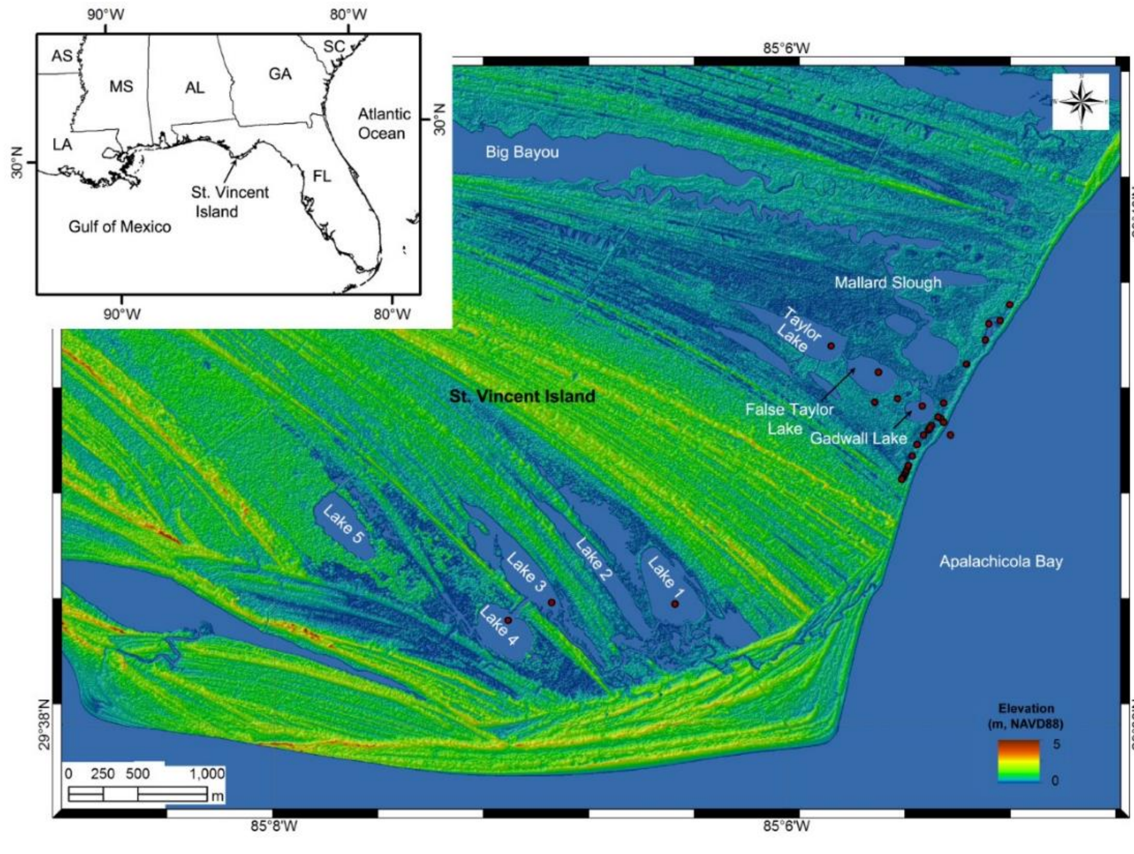

Figure 1 The core site in Gadwall Lake on St. Vincent Island, Florida.

2. Methods

2.1 Field Work

A sample core was taken from the central part of Gadwall Lake, on St. Vincent Island, Florida using a piston corer. Caution was taken to minimize disturbance at the water/sediment interface in the field. However, the top few centimeters of the core were disturbed during core retrieval and transport. The core was transferred back to Coastal Carolina University where it was split into two halves lengthwise. One half was used for grain-size, foraminifera, ^{210}Pb and ^{14}C dating analysis and the other half was archived and used as supplement for samples of the working half. The grain-size analysis was done separately while this study focuses on foraminifera extraction and identification.

2.2 Data Collection: Grain Size

The working half of the core was subsampled at 0.5 cm vertical solution for grain size analysis using a CILAS 1190 laser particle size analyzer. The grain-size subsamples were taken by excavating ~0.5 grams sediments from the center of the core at designed depth, pretreated in sequence with (1) 6 ml 30% hydrogen peroxide to remove organic matter; (2) boiling for 1 minutes to remove excess hydrogen peroxide; (3) 3 ml 0.1M sodium hexametaphosphate for dispersion before being measured with a preset standard operation procedure. Potential event layers were associated with the presence of higher concentrations of sand and the sand concentration at the surface layer corresponding to Hurricane Michael was used as a threshold to identify events with magnitude similar to Michael.

2.3 Foram Extraction and Identification

From each potential event layer identified by the grain size analysis and a number of layers with no event deposits from grain-size analysis (Table 1), 2-3 cm^3 of sample were taken and soaked in water overnight. After soaking, the samples were hand-sieved through a 63μm filter sieve and the larger than 63 μm particles were sieved through 500μm filter sieve. The particles smaller than 500μm were either air dried or oven dried at 60°C (Table 1) for further foraminifera extraction.

Viewing and identifying foraminifers was performed using a Leica Zoom 2000 microscope. Forams were extracted under a microscope from dried sediment using a very thin brush. This brush was used to place them onto a sample slide, which was then used for identification. Identification was determined by referencing previous literature: Poag (2001), Kemp et al (2009), Horton and Edwards (2006), Twichell et al (2009), and Haller et al (2019) (Table 2). From these identifications, the forams were grouped into three categories: *Ammonia* spp., *Elphidium* spp., and other. *Ammonia* and *Elphidium* are two calcareous genus of forams that are commonly found in the Apalachicola Bay (Twichell et al 2009), and is used as evidences of overwash. Common marsh species were the *Jadammina macrescen*, *Arenoparella Mexicana*, and *Trochammina inflate* which were grouped together under the category of other due to their general paucity in my sample. Photos of identified foram tests were taken through the eye pieces of the microscope

2.4 Data Analysis

The total number of foram tests and species diversity were compared to the sand grain concentration in each layer to verify the event deposits

Table 1 The sample depth, drying method, and core half are recorded below.

Depths (cm)	Oven or aired dried	Event or Non Event Layer	Other notes
1-2	Oven	Event	Working half
2-3	Oven	Event	Working half
3-4	Aired	Event	Archive half
6-7	Aired	Non event	Working half
8-9	Aired	Event	Archive half
11-12	Aired	Non event	Archive half
17-18	Aired	Event	Archive half
25-26	Oven	Non event	Archive half
33-34	Oven	Event	Working half
37-38	Aired	Event	Working half
38-39	Aired	Event	Archive half
42-43	Aired	Event	Working half
47-48	Aired	Non event	Working half
57-58	Aired	Non event	Working half
67-68	Aired	Non event	Working half
82-83	Aired	Event	Working half
100-101	Aired	Event	Working half

Table 2 The names, images, and characteristics used to identify forams

Name	Images	Characteristics
Ammonia spp	(Figure S1, Figure S2)	*Ammonias* were identified by deep sultures and umbilicus and a trochospiral on the ventral side. (Poag 2001)
Elphidium spp	(Figure S3)	*Elphidiums* have depressed umbilicus with papillae ornament sultural pits (Horton and Edwards 2006, Twichell et al 2009, Poag 2001, Cushman 1930)
Trochammina inflate	(Figure S4)	*Trochammina I.* are composed of finely detrital grains that is brown in color. Aperture an interiomarginal slip with a lip (Kemp et al 2009, Horton and Edwards 2006)
Haynesina Germanica	(Figure S5, Figure S6)	*Haynesina G.* were classified by Calcitic withradially arrange crystalities that look glassy in appearance. The sultures are depressed that depesses more towards the umbilicus (Horton and Edwards 2006)
Arenoparrella Mexicana	(Figure S7, Figure S8)	(Kemp et al 2009, Haller et al 2018)

3. Results

3.1 Grain Size

Sand concentrations in Gadwall Lake 1 were generally found to be in the range of 0-5%. A higher sand concentration, 25-45%, was found in the first few centimeters, with a dip around 6 cm, followed by a slight spike and a larger spike at 10 cm. Sand percentages spiked to high (35-40%) at depths of 18 cm, 32 cm, 41 cm, and from 80-84 cm. Extremely high sand percentages (50% or higher) were measured at 38 cm and 40 cm (Figure 2).

3.2 Foraminifers

Forams were found in the greatest abundance in the surface layers, up to 11 cm. Low numbers of forams were found at the 33 cm and 42 cm layers (Table 3, Figure 2). *Ammonia spp.* was the most abundant foram genus in all layers except the 11 cm, 33 cm and 42 cm layer (Table 3, Figure 2). At these layers a combination of forams were more abundant (Table 3, Figure 2). Beyond these layers forams were no longer detected.

3.3 Comparison

A high sand percentage with an abundance of forams was found until the 10 cm layer. At 33 cm and 42 cm, a lower amount of forams was found, despite high concentrations of sand (Figure 2). In the majority of the deep layers tested, there was a high concentration of sand, but no forams detected.

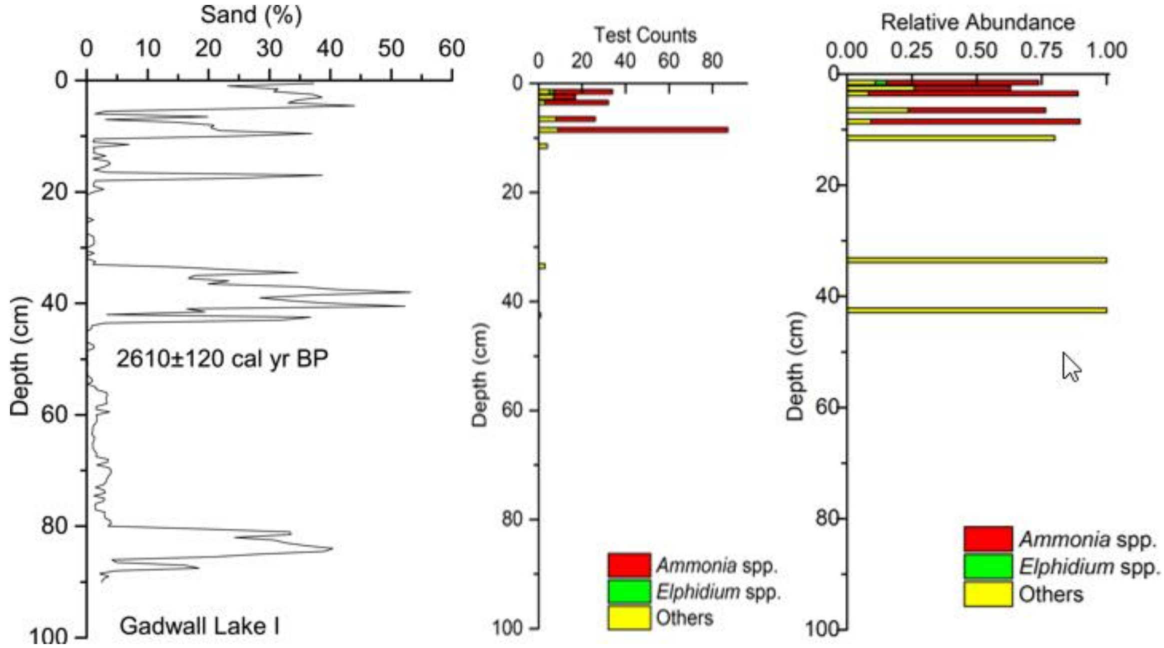

Figure 2 The comparison of the sand concentration with the foraminiferas in a sediment core taken from Gadwall Lake from St. Vincent Island, Florida.

Table 3 The forams classified into species for each depth

Depths (cm)	*Ammonia* spp.	*Elphidium* spp.	Other	Total
1-2	34	7	5	46
2-3	17	3	7	27
3-4	32	1	3	36
6-7	26	0	8	34
8-9	87	1	9	97
11-12	1	0	4	5
17-18	0	0	0	0
25-26	0	0	0	0
33-34	0	0	3	3
37-38	0	0	0	0
38-39	0	0	0	0
42-43	0	0	1	1
47-48	0	0	0	0
57-58	0	0	0	0
67-68	0	0	0	0
82-83	0	0	0	0
100-101	0	0	0	0

4. Discussion

4.1 Event Indicators

High sand concentrations were found in the surface layers of Gadwall Lake, which were believed to be caused from the overwash of Hurricane Michael. In the surface layers, 1-4cm, there were large amount of calcareous bay forams, along with high sand concentration. Apalachicola Bay has considerably concentration of calcareous forams (Twichell et al 2009) which were then washed into Gadwall Lake. This wash came from flooding caused by Hurricane Michael. At 6-7 cm, there were more bay species present with a low sand concentration, which indicates a nonevent layer. This implied that the forams can be used as an indicator for events. In the top 4 cm and 8-9 cm, a high sand concentration was always accompanied by higher concentrations of forams. These forams were composed of mainly *Ammonia* spp., which was found primarily in the Apalachicola Bay. In the deeper layers where forams were present, there was a high sand concentrations which was believed to be an event. In the other deeper layers, there were no evidences of forams whether or not they were event layers. As the surface layers were brought in by Hurricane Michael, it was theorized that the high sand concentrations in deeper levels were caused by similar events. These similar events would have also accounted for the higher concentrations of forams. Calcareous forams, such as *Ammonia spp* and *Elphidium spp.,* are an indicator of bay and estuarine environments, with shallow water depths, variable salinity, and fluvial influences that are composed primarily of silty and sandy muds (Osterman et al 2009). The foraminifera concentrations correspond to high levels of sand in the top layers were used to indicate major storm events such as Hurricane Michael, a category 5 hurricane. The deeper layers showed little to no forams, which was believed to be caused by poor preservation, however the increase in sand concentrations still indicated major events.

4.2 Preservation of Forams in the Pond Sediments

Foraminifers were present in the surface layers that indicated an event, but not in deeper layers. This lack of forams was most likely due to poor preservation. The lack of foraminifera tests at deeper depths could be caused by a variety of things. For example, increased exposure to pCO_2 concentrations in the water could lead to the dissolutions of forams in the layer. The CO_2 from the atmosphere was absorbed in the water, which would cause water to become more acidic which would result in the dissolution of the calcareous forams. (Haynert et al 2011). This could have occurred before the forams had the chance to be buried, and thus preserved. Another theory form the lack of forams is that the combination of bioturbation and the mixing of sediment causes the lack (Hippensteel 2008). Bioturbation increases with slowed deposition of sediment, and could cause the destruction of forams prior to burial. At the same time, the mixing of the sediment is capable of destroying forams after burial. Bioturbation, such as from fiddler crabs, and other horizontal sediment transport can destroy any short term stratigraphic signal, such as from seasonal changes or small storms. This implies that only large weather events would leave traces of forams as evidence (Hippensteel 2008).

4.3 Further studies

Further studies can be performed to gain a better understanding of what leads to the lack of forams in the deeper layers. This would help to gain a better understanding of how to use the presence of forams to indicate historic events. In order to gain a better understanding of the preservation of forams in deeper layers, it is important to expand the area of study. Expanding the area of study to include other lakes, and potentially other areas, is important to help indicate whether foram preservation varies regionally or follows an overall trend. Further study could also include testing the results of other event indicators to see if they match the results of grain size, or if there are similar problems to the use of forams.

5. Conclusion

Despite the lack of preserved forams in deeper layers, the surface layers were able to show a correlation between the grain size analysis and the forams. The top 4 centimeters of sediments indicated the overwash of sediment from Hurricane Michael. This overwash was from Apalachicola Bay, which had higher sand concentrations, and higher levels of calcareous foraminifera from genus *Ammonia.* At 6-7 cm there was a lower concentration of sand with a higher amount of marsh forams which indicates a nonevent. High sand concentrations along with a large count of calcareous forams indicates an event layer. Calcareous forams are indicators of estuarine environments, with variable salinities. This allowed them to be used as an indicator of storm events in shallow layers, however the lack of their preservation made them non-ideal for deeper layers. The poor preservation was likely caused by a number of issues such as prolonged pCO2 exposure, bioturbation and mixing of the soils.

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Appendix

Figure S1 Ventral side of an *Ammonia* that was extracted from Gadwall Lake 2-3 cm.

Figure S2 Dorsal side of an *Ammonia* that was extracted from Gadwall Lake 2-3 cm.

cm.

Figure S3 Image of an *Elphidium* that was extracted from Gadwall Lake 2-3 cm.

Figure S4 Image of a *Trochammina inflate* that was extracted from Gadwall Lake 2-3 cm.

Figure S5 Image of a *Haynesina Germanica* that was extracted from Gadwall Lake 1-2 cm.

Figure S6 Image of a *Haynesina Germanica* that was extracted from Gadwall Lake 1-2 cm.

Figure S7 Dorsal side of an *Arenoparrella Mexicana* that was extracted from Gadwall Lake 42-43 cm.

Figure S8 Ventral side of an *Arenoparrella Mexicana* that was extracted from Gadwall Lake 2-3 cm.